Predicting Impact of a Restoration Project on River Dynamics: A Case History

Burchard H. Heede

General Technical Report RM-62
Rocky Mountain Forest and
Range Experiment Station
Forest Service
U.S. Department of Agriculture

Abstract

Frequently forest hydrologists neither possess hard-core information for impact evaluations of restoration projects nor the time to gain this information. The report demonstrates how theory and experience gained elsewhere can be applied in such situations.

Keywords: Channel dynamics, aggradation, degradation, armoring, Salmon River.

Predicting Impact of a Restoration Project on River Dynamics: A Case History

Burchard H. Heede, Principal Hydraulic Engineer
Rocky Mountain Forest and Range Experiment Station[1]

The Land Manager's Dilemma

Interactions exist between streams and their environment (Shen 1972). In small streams the interaction may be so strong vegetation such as forests influences bedload movement and slope adjust processes (Heede 1972). Land management practices can, therefore, affect, and sometimes control, stream hydraulics. Projects dealing with watershed restoration (erosion control) may have severe influences because water and sediment delivery can be greatly changed in volume as well as lag time. The degree of influence not only depends on the type of stream environment but also on the condition of the stream itself, for example, aggrading or degrading channels, stream systems within or outside of dynamic equilibrium, and availability of large grain sizes and their distribution in the bed. Data are required to project and quantify expected management influences. Generally, for land (watershed) data such as climate, soils, geology, and vegetation are at hand; but for streams the required data are seldom available. These would include information on suspended and bedload transport, bed material sizes, stream competency, including dynamic equilibrium condition, and channel geometry. In addition, records on flow rates and other flow characteristics are needed.

The acquisition of missing data takes time. Usually this is not available due to pressing problems. Without hard-core data, projection equations (quantifications) cannot be developed. For such cases, the author suggests using available theory and experiences gained elsewhere to project the general direction of future stream developments as influenced by a given practice. This knowledge will be helpful in making management decisions.

[1]Central headquarters maintained at Fort Collins, in cooperation with Colorado State University. Author is at the Station's Research Work Unit at Tempe, in cooperation with Arizona State University.

The objective of this report is to demonstrate a historical case for which essential data were missing but project execution could not be postponed. Although a specific situation will be described, the approach, using theory and experience in combination with some existing data, can serve as an example for evaluations required under different circumstances. The reader is urged to recognize the great importance of apparent mechanics and dynamics of the river system for predicting the degree of influence of a proposed restoration project.

The Scope

Evaluations of critical stream locations must consider the stream as a whole, because many interactions exist between the different stream reaches and their dominant hydraulic variables. Streams are dynamic systems with a built-in tendency for adjustment to change (Heede 1975). Dump Creek's junction with the Salmon River represents a critical location because of past treatment and future developments. Changes at this junction may influence both downstream and upstream reaches. The junction could also be influenced by changes in upstream or downstream reaches independent of developments at Dump Creek.

During the last quarter of the 19th century, mining was big business in the Salmon River Mountains, and some of this activity was concentrated in the headwaters of a drainage later known as Dump Creek. Dredging and other placering operations were used for mining. The Dump Creek watershed has an extremely diversified geology, ranging from sedimentary materials, partially of volcanic origin, to igneous rocks (granites and basalts). Much of the soil parent material was granitic glacial till leading to formation of predominantly sandy soils. Typical of tills, intercalated lenses of sand and gravel are

common and mostly of local extent. Although surface disturbances by mining operations brought subsurface gravel and boulders to the surface, the greatest detrimental impact was produced when Moose Creek was apparently diverted into the present Dump Creek. This diversion shortened the watercourse length and thereby increased bed gradients and flow velocities considerably. This produced a deep gully having widths reaching 400 feet (figs. 1 and 2). Project planners estimate the annual sediment yield of Dump Creek reaches 30,000 to 40,000 cubic yards. Based on the geology of the raw valley sides, it is estimated about 90 % of this load is suspended sediment (sand sizes and smaller), and 10% bedload (particle sizes predominantly larger than sand size). This relationship was also found in the Salmon River headwater drainage by Emmett (1975) at Challis, Idaho (80 miles upstream from the Dump Creek junction).

Part of the coarse bedload from the Dump Creek drainage formed an alluvial fan at the creek's mouth. However, practically all the suspended load was transported downstream by the Salmon. The growing fan forced the Salmon River to undercut the Salmon River road (fig. 3). This road serves local residents, log transportation, and other land management activities downstream from North Fork.

Figure 1.—Upstream view of upper reach of Dump Creek that developed into an immense-sized gully. Arrow points to a man standing on debris at right gully side slope.

Figure 2.—Upstream view of lower reach of Dump Creek depicting the immensity of gully growth. Arrows point to volcanic plugs and dikes excavated by gully erosion.

The tendency for riverbed aggradation below the Dump Creek junction is indicated by long-term aerial photo observations, bar formations, frequency of bar overflows, and braiding tendencies of the river.

Planned Project

Objectives of the Dump Creek Restoration Project are to reduce the large amounts of sediment entering the Salmon River, to prevent future undercutting of the river road at the place of junction, and to introduce erosion control measures in and alongside Dump Creek. Forest administration had considered several alternatives and decided the objectives could be accomplished best with least amount of funds by diverting the flow back into Moose Creek. This will decrease flows into Dump Creek to a fraction of pre-project volumes thus reducing sediment transport.

Present Characteristics of the Salmon River

Emmett (1975) showed sedimentation is large in the Salmon River above the Dump Creek junction. Average annual sediment yield at Challis was estimated to be 2.5 million cubic yards. Dump Creek transports only 1.2 to 1.7% of this amount. The 5-mile reach between North Fork and Dump Creek, known as Deadwater, is of special interest to this study because it directly influences developments at the Dump Creek junction. As the name implies, the

water flows very sluggishly through the Deadwater reach (fig 3), and compared to adjacent upstream reaches, its carrying capacity for sediment is very low. The average channel gradient through Deadwater is 0.00088 ft/ft (or 0.088%), which represents 33% of the reach gradient above Deadwater and 7.4% of the reach below Deadwater, located between Dump Creek and Moose Creek junctions.

Aerial photographs, taken at intervals up to 31 years, covered the peak flow period in 1974 when the largest flood on record occurred. They show a channel control exists on the upstream side of the alluvial Dump Creek fan. This control is signified by an abrupt change of flow regime: still water upstream (also at high water stages), and shooting flows below along the alluvial fan (fig. 3).

Could the fan itself be a control? Apparently this was assumed by the Corps of Engineers when they started artificially trenching the alluvial fan in 1962. Of an estimated 90,000 cubic yards, 12,000 yards were excavated. The next spring flow of Dump Creek buried the excavation again, and the project was abandoned. Corps records on this project are not available.

Figure 3.—The Dump Creek sediment fan at junction with Salmon River. Flow is from left to right. Note the still water surface upstream from junction in contrast to rapids downstream.

Strong geologic and hydraulic evidence as well as theoretical considerations indicate the fan itself was partly produced by the Salmon River channel control. Aerial photographs indicate lineal geologic-stratigraphic features are aligned with the flow regime breaking point. Before this investigation was conducted, Forest Service professionals proposed a volcanic dike existed at the control site. Indeed, the slumped valley side slopes of Dump Creek exhibit buried volcanic landforms such as plugs and dikes (fig. 2). Yet, it is also possible another geologic feature such as a disconformity (created by a fault, etc.) is responsible for this control.

Hydraulically, it is amazing that in spite of exceptionally large flows the fan perimeter at the mouth of Dump Creek changed only a minor amount over the years. This astounding fact was true for the upstream part of the fan which remained practically untouched during a record flood in 1974 when peak flow of the Salmon River exceeded that of Dump Creek by a factor of more than 25. This flood was the largest on record, and it was estimated to have a recurrence interval of 80 years. At this interval a high peak flow estimate by the Forest was 600 cfs for Dump Creek. The second highest peak flow on record for Salmon River was 16,500 cfs at Salmon (USGS 1965). The overriding magnitude of Salmon's flow should have altered the alluvial fan considerably. That it didn't indicates existence of an effective bed control.

The 13-mile reach downstream from Dump Creek to Spring Creek junction reflects sediment delivery by Dump Creek (fig. 4). Four larger bars, comprising areas of more than 2 acres, exist in this reach (fig. 5). These bars are frequently moving. Compared with reaches upstream from Dump Creek, bar frequency is much smaller downstream.

Aggradation in the channel reach is combined with overtopping of bars by high flows forming newly incised channels. Thus, braiding patterns occur. At other times heavy, sediment laden, rising-stage flows plug channels with deposits; and the less sediment laden recession flows cut new channels resulting in a shifting flow pattern (fig. 6). Two of the larger point bars, essentially part of the flood plain, are in private ownership and are used for agricultural production (mainly hay).

Below Spring Creek the valley bottom narrows producing greater flow depths and higher velocities (fig. 7). Bars are practically absent in the reach terminating at the Pine Creek bridge, approximately

Figure 4.—The Salmon River downstream from the Dump Creek fan. Bar formations indicate high sediment loads. Flow is from left to right.

5 river miles downstream from Spring Creek. The valley becomes V-shaped and the river is geologically controlled by closely-spaced rapids for at least 6 miles (fig. 8). The investigations stopped at the rapids because they are effective as a present and future control. Regardless of future flow and sediment discharges only small changes will occur at this location (measurable only on a geologic time scale). The Lewis and Clark Expedition encountered this same control on August 24, 1805, and decided to discontinue river travel (DeVoto 1953). Today's name of this reach is the "River of No Return."

Figure 5.—Two of the larger point bars (arrows) existing in the 13-mile-reach downstream from the Dump Creek fan. The bar at left of figure has agricultural use, but is not free from inundations.

Expected Impact from Project

The preceding discussion demonstrates the dominant dynamics of the Salmon River in the reaches adjacent to Dump Creek. Following project initiation, Dump Creek's water discharge and sediment delivery should be decreased to about one-tenth of its present rate. With the smaller flows the average particle size (mainly of the bedload) will be much smaller than in the past. On the other hand, large quantities of easily transported sediment will continue to be produced from the raw valley side slopes, still much steeper than their angle of repose. Thus, suspended load and bedload will continue to be deposited into Salmon River but at a much slower rate than at present.

It is suspected that during the first years after project initiation, Moose Creek's washload (silt and clays, mainly) will offset some of the losses of suspended load. Unfortunately, even point data on Dump Creek's water and sediment yields are not available. Moose Creek's descent from the mountains to Salmon River follows a well armored channel bed (fig. 9). This is characterized by several locations of extreme bed roughness produced by

Figure 6.—This bar indicates the shifting flow patterns as influenced by low, high, and exceptionally high flows.

Figure 7.—In contrast to the reach illustrated in figures 4 and 5, lateral stream movement (adjustment) is not possible in this reach. Flow velocities are high and major bars absent. Practically all sediment is carried through this section.

Figure 8.—Where the Salmon River narrows between steep mountain slopes, surface water waves indicate bedrock controls (rapids) on the river bed.

room-size boulders that break flow velocities and, if available, prevent delivery of coarse materials. Therefore, our concern must be centered on Dump Creek's influence on the Salmon.

Two expected changes in sediment delivery by Dump Creek of concern are (1) a decrease in sediment load, and (2) a decrease in average particle size of the load (Maddock 1973). The drastic decrease in sediment load will force the Salmon River to adjust its bed slope to a lower gradient. As well known from other rivers (e.g. River Rhine and Colorado River), where the load has been manipulated by man, adjustment leads to degradation in the reach downstream from the point of sediment withdrawal (or reduction) and to aggradation of the excavated material farther downstream (Borland and Miller 1960). On the Colorado River, where practically all sediment was withdrawn by Hoover Dam (about 160 million tons annually), the stream degraded a maximum of 15 feet in 14 years. Adjustment still proceeds by lateral movements, mainly taking out bars not sufficiently armored (Gessler 1971). Such bed cuttings have a wedge-shaped longitudinal profile with the deepest cut at the point of sediment withdrawal.

The sediment discharge of Colorado River was 800 times greater than the Salmon at Challis, 80 river miles upstream from Dump Creek. Although data are not available to calculate depth of cuttings in Salmon River, past predictions by experts in the field show an accuracy of only one order of magnitude, for example, River Nile below Aswan Dam (Hammad 1972). Since the Colorado River project totally removed all sediment, the impact would be more severe than would be expected by the Dump Creek Project. A conservative estimate, based on Colorado River data, would be a maximum bed lowering of 1 to 1.5 feet at Dump Creek. The cut would not be expected to reach Pine Creek bridge, about 18 river miles downstream from Dump Creek. Thus, the bridge buttresses, armored by heavy boulders, will not be affected. Indeed, some aggradation may take place upstream from the bridge where relatively minute point and cross-over bars may be enlarged. Maximum aggradation of less than 1 foot is expected since most of the material

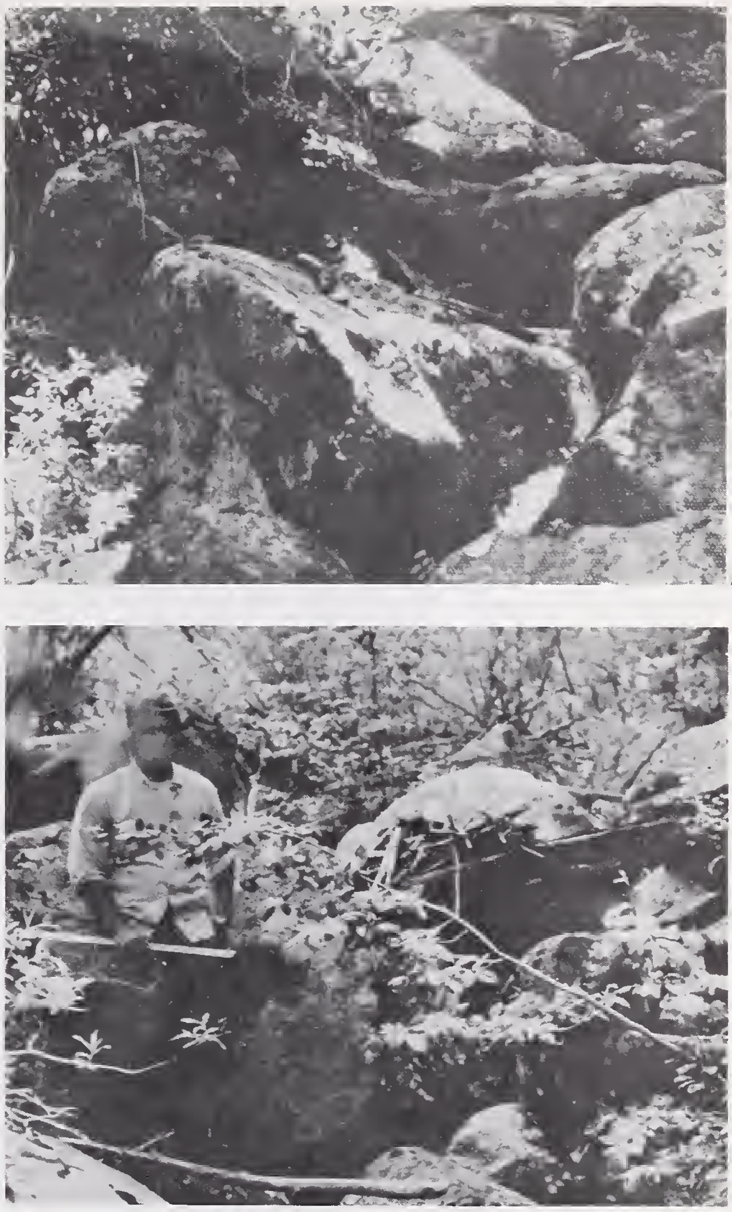
excavated below Dump Creek junction will be carried through the confined channel reach into the rapids downstream from the bridge.

Where valley bottoms are wide, slope adjustment will take place by lateral stream movements (Neill 1971, Heede 1977). At present, four flood plains exist that developed from point bars and now support a braided flow pattern. Here, the original meander may be reestablished by lateral movement. But, again, changes will be relatively small, not exceeding a few feet.

In conjunction with deep bed cutting, changes in the channel gravel-boulder armor will most likely occur. This will occur because of a decrease in the average particle size of the load. Several investigators (Gessler 1965, Little and Mayer 1976) have shown streams conveying water through alluvium tend to be armored with the larger particle sized material. However, we should recognize the top layer of the bed is made up predominantly of these larger sizes and also contains the same smaller grains present in the underlying layer. During the armoring process, sorting occurs and the finer fractions are eroded away leaving the larger particle sizes concentrated in the top layer, although there is no distinct boundary between the erodable and non-erodable grain size. When the sediment source and flow magnitudes are altered, the armor layer is changed. When this armor layer is changed, new bed levels develop parallel to the original bed level.

In our case, Dump Creek will decrease its estimated volume of water by nine-tenths. The process resulting from this change can be visualized as follows: the larger particles that presently make up the bed will not be replenished by Dump Creek. Since much smaller sizes will be deposited, flows in the Salmon River will pick up more of these deposits than before the project. In addition, selective transport of smaller grain sizes available in the top layer continues in the bed of the Salmon River. The combined effect will be a lowering of bed level in the upstream portion of the Salmon reach below the junction with Dump Creek. Thus, deep cutting will be caused by reducing both load and particle size. The maximum cutting below the junction is estimated to be about 2 feet. Cutting will proceed gradually, and little change in sediment will occur at the tributary junction because a sizeable amount of material is still available for transport downstream, and sediment delivery will not be fully stopped.

Changes in the bed level associated with alignment will be beneficial. At present, Dump Creek forces the Salmon River toward the road at the point of junction leading to bank undercutting. After project initiation, this bank can be safely protected by revetment with a minimum of effort because the effect of Dump Creek will be reduced. The flood plains below Dump Creek were frequently inundated in the past, causing damage to the private agricultural land. Consequently the owner expended much effort in the past to construct dikes to protect his land. Natural bed deep cutting should eliminate this need. Less sediment coming from Dump Creek will increase the ability of the Salmon River to transport sediment loads through the reach and over time will decrease (or eliminate) such problems as braiding, and flooding of low-lying lands.



A

B

Figure 9.—The bed of Moose Creek is well armored on its descent from the mountains to the Salmon River. (A) Upstream view; (B) Man gives scale to the size of the bed armor material.

Some undesirable effects which may arise from the project are channel wanderings, until a new quasi-

equilibrium stream condition is established. These may result in cutting of outside meander banks but will only be of minor magnitude as compared to present-day conditions. If it should be judged necessary, much less effort will be required for bank protection work than training the presently aggrading reach.

There may be some aggrading in the reach between Spring Creek and Pine Creek, causing small-scale enlargements of present small point and cross-over bars. These changes will be hardly noticeable because the reach is generally well defined in a relatively narrow valley bottom.

Without hard-core data, it is difficult to estimate the time necessary for the Salmon River to adjust to post-project conditions. The rate of adjustment will depend on high flow frequencies and magnitudes. Using Colorado River as a benchmark, it is believed the Salmon River will require 5-10 years to adjust to project changes.

The evaluation of the project's impact on the Salmon River below the "River of No Return" was not attempted because the water and sediment from Dump Creek made up only a minute amount of this total.

It is recommended, if the project is done, post-treatment behavior of Salmon River be monitored in the reaches below Dump Creek and Moose Creek as well as Dump Creek and Moose Creek in order to test the model predictions. Furthermore, such tests will increase information on stream dynamics. Too often this prediction aspect is omitted and with this the opportunity to strengthen our knowledge.

Literature Cited

Borland, Whiteney M., and Carl R. Miller. 1960. Sediment problems of the lower Colorado River. Proc. Am. Soc. Civ. Eng. HY4:61-87.

DeVoto, Bernard, ed. 1953. The journals of Lewis and Clark, p. 227. Houghton Mifflin Co., Boston. 504 p.

Emmett, William W. 1975. The channels and waters of the upper Salmon River area, Idaho. Geol. Surv. Prof. Pap. 870-A, 116 p.

Gessler, Johannes. 1971. Aggradation and degradation. *In* River Mechanics, Vol. 1, p. 8-1 to 8-24. Hsieh Wen Shen, ed. H. W. Shen, P. O. Box 606, Ft. Collins, Colo. 80521.

Gessler, Johannes. 1965. The beginning of bedload movement of mixtures investigated as natural armoring in channels. Translation T-5, W. M. Keck Lab. of Hydraulic and Water Resour. Div. of Eng. and Applied Sci., Calif. Inst. of Tech., Pasadena, Calif. 89 p.

Hammad, Hammad Y. 1972. River bed degradation after closure of dams. Proc. Am. Soc. Civ. Eng. HY4: 591-607.

Heede, Burchard H. 1972. Influences of a forest on hydraulic geometry of two mountain streams. Water Resour. Bull. 8(3):523-530.

Heede, Burchard H. 1975. Mountain watersheds and dynamic equilibrium. p. 407-420. *In* Watershed Manage. Symp., ASCE Irrig. Drain. Div., [Logan, Utah, Aug. 11-13, 1975].

Heede, Burchard H. 1977. Influence of forest density bedload movement in a small mountain stream. p. 103-107. *In* Vol. 7, Hydrology and water resources in Arizona and the Southwest. Proc. 1977 Meet. Ariz. Sect., Am. Water Resour. Assoc. and Hydrol. Sect., Ariz. Acad. Sci. [Las Vegas, Nev., Apr. 1977].

Little, William C., and Paul G. Mayer. 1976. Stability of channel beds by armoring. Proc. Am. Soc. Civ. Eng. HY11:1647-1661.

Maddock, Thomas, Jr. 1973. A role of sediment transport in alluvial channels. Proc. Am. Soc. Civ. Eng. HY11: 1915-1931.

Neill, Charles R. 1971. Riverbed transport related to meander migration rates. Proc. Am. Soc. Civ. Eng. WW4:783-786.

Shen, Hsieh Wen, ed. 1972. Environmental impact on rivers. H. W. Shen, P.O. Box 606, Ft. Collins, Colo., 20 chapters.

U.S. Geological Survey. 1965. Water resources data for Idaho, Part I. Surface Water Records, p. 237. U.S. Geol. Surv., Water Resour. Div., 914 Jefferson St., Boise, Idaho. 284 p.

Agriculture — CSU, Fort Collins

Heede, Burchard H. 1979. Predicting impact of a restoration project on river dynamics: A case history. USDA For. Serv. Gen. Tech. Rep. RM-62, 8 p. Rocky Mt. For. and Range Exp. Stn., For. Serv., U.S. Dep. Agric., Fort Collins, Colo. 80526.

Frequently forest hydrologists neither possess hard-core information for impact evaluations of restoration projects nor the time to gain this information. The report demonstrates how theory and experience gained elsewhere can be applied in such situations.

Keywords: Channel dynamics, aggradation, degradation, armoring, Salmon River.

Heede, Burchard H. 1979. Predicting impact of a restoration project on river dynamics: A case history. USDA For. Serv. Gen. Tech. Rep. RM-62, 8 p. Rocky Mt. For. and Range Exp. Stn., For. Serv., U.S. Dep. Agric., Fort Collins, Colo. 80526.

Frequently forest hydrologists neither possess hard-core information for impact evaluations of restoration projects nor the time to gain this information. The report demonstrates how theory and experience gained elsewhere can be applied in such situations.

Keywords: Channel dynamics, aggradation, degradation, armoring, Salmon River.

Heede, Burchard H. 1979. Predicting impact of a restoration project on river dynamics: A case history. USDA For. Serv. Gen. Tech. Rep. RM-62, 8 p. Rocky Mt. For. and Range Exp. Stn., For. Serv., U.S. Dep. Agric., Fort Collins, Colo. 80526.

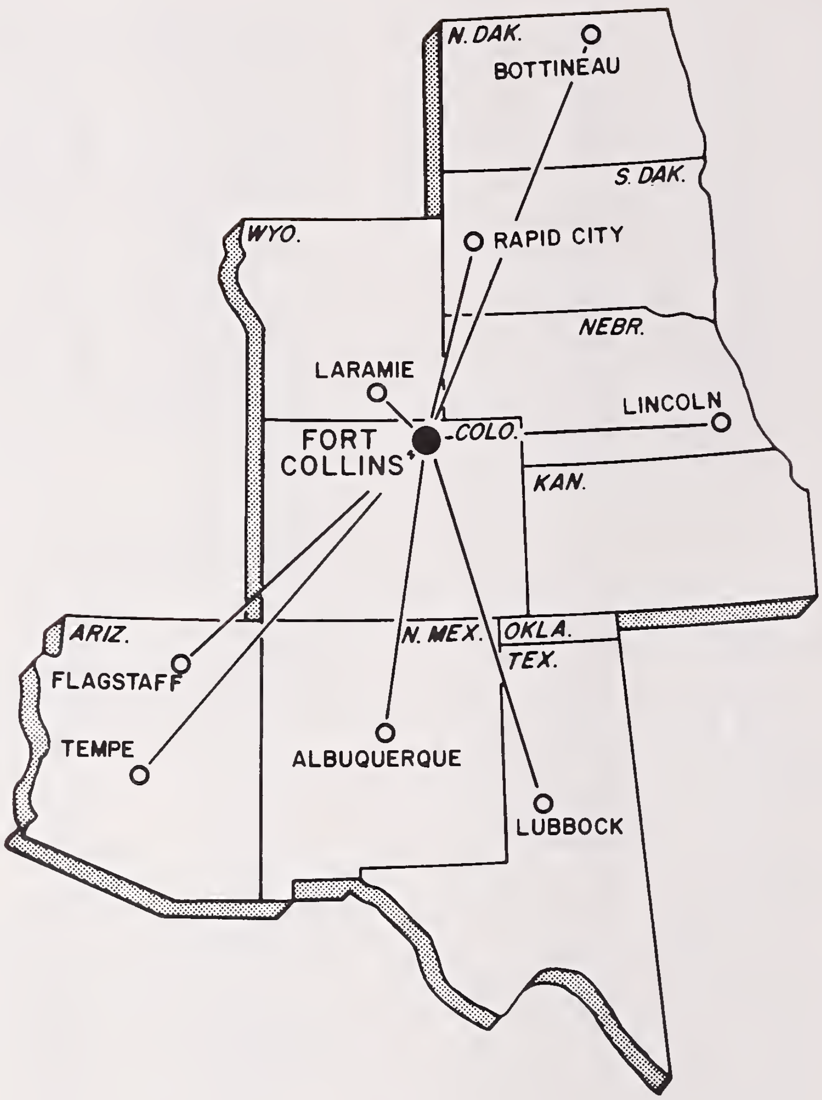
Frequently forest hydrologists neither possess hard-core information for impact evaluations of restoration projects nor the time to gain this information. The report demonstrates how theory and experience gained elsewhere can be applied in such situations.

Keywords: Channel dynamics, aggradation, degradation, armoring, Salmon River.

Heede, Burchard H. 1979. Predicting impact of a restoration project on river dynamics: A case history. USDA For. Serv. Gen. Tech. Rep. RM-62, 8 p. Rocky Mt. For. and Range Exp. Stn., For. Serv., U.S. Dep. Agric., Fort Collins, Colo. 80526.

Frequently forest hydrologists neither possess hard-core information for impact evaluations of restoration projects nor the time to gain this information. The report demonstrates how theory and experience gained elsewhere can be applied in such situations.

Keywords: Channel dynamics, aggradation, degradation, armoring, Salmon River.


N. DAK.
BOTTINEAU
S. DAK.
WYO.
RAPID CITY
NEBR.
LARAMIE
LINCOLN
FORT COLLINS
COLO.
KAN.
ARIZ.
N. MEX.
OKLA.
TEX.
FLAGSTAFF
TEMPE
ALBUQUERQUE
LUBBOCK